Astronomical Observational Uncertainties

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Introduction

Uncertainty in Astronomy

- Limits to current level of understanding of a phenomenon
- Phenomenon complexity
- Restrictions in instrumentation
- Observer bias
- Observer experience
- Observing conditions

Astrostatistics

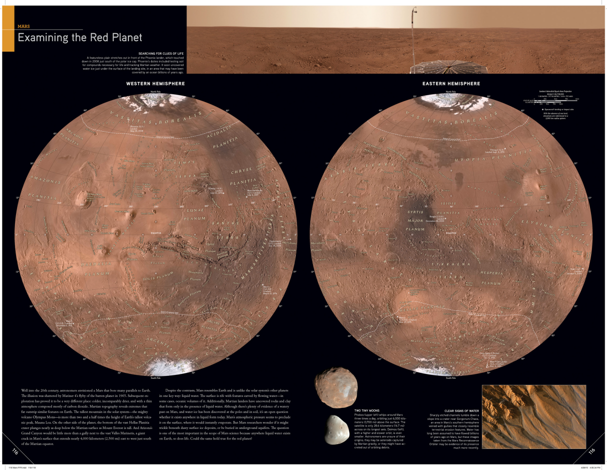
- Astrostatics addresses uncertainty with statistical analyses and data mining of astronomical data
- Astrostatistics community
  - Astronomers and astrophysicists
  - Statisticians
  - Computer information scientists
- Organizations
  - The International Astrostatistics Association (IAA)
  - International Statistics Institute (ISI) Astrostatistics Committee
  - Astrostatistics Working Groups of the International Astronomical Union (IAU)
  - American Astronomical Society (AAS)

Astrostatistics Projects

- Water on Mars
- Sunspot counts
- Mira masers
- Interstellar regional density and star formation
- Radio-Active Galatic Nuclei and the early universe

Locating Water on Mars

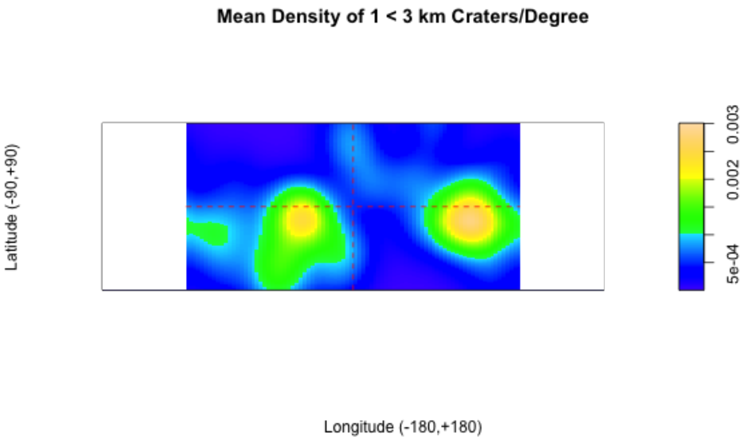
Mars crater global distribution



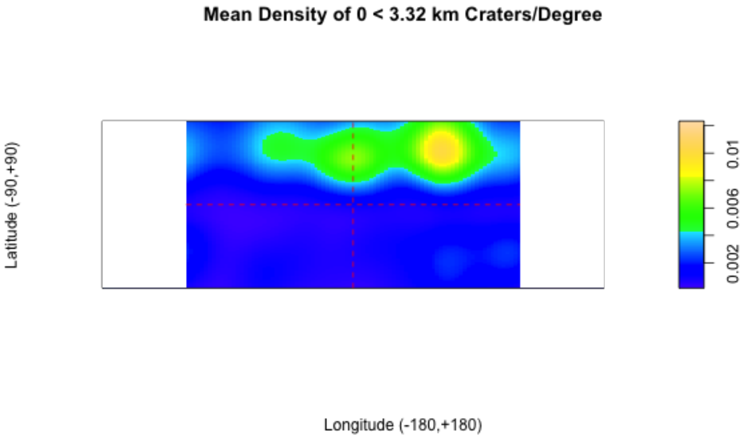
Water Location Hypothesis

- Impact crater ejection layer patterns indicate surface or subsurface water
- More than one layer surrounding an impact crater suggests water interacting with ejected soil
- Layers with radial patterns have little to no water in the soil
- Compare spatial distributions of multi-layer ejecta to radial ejecta spatial distributions
- Radial ejecta the "control" group
- May be applicable to other moons and planets

Radial ejecta spatial distribution

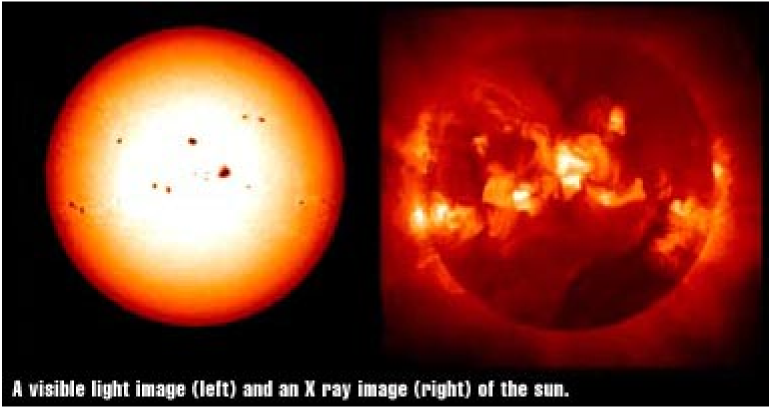


Double layer ejecta spatial distribution



Sunspot Counts

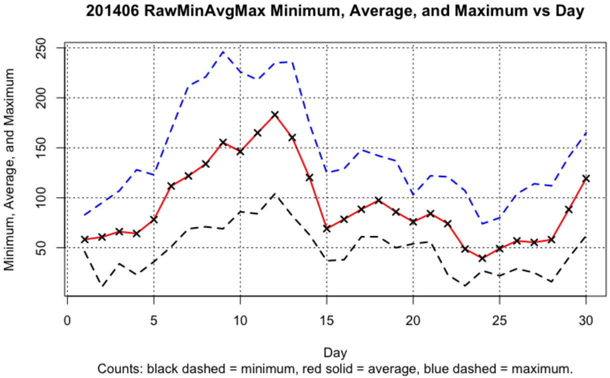
Solar activity visually and in X-rays



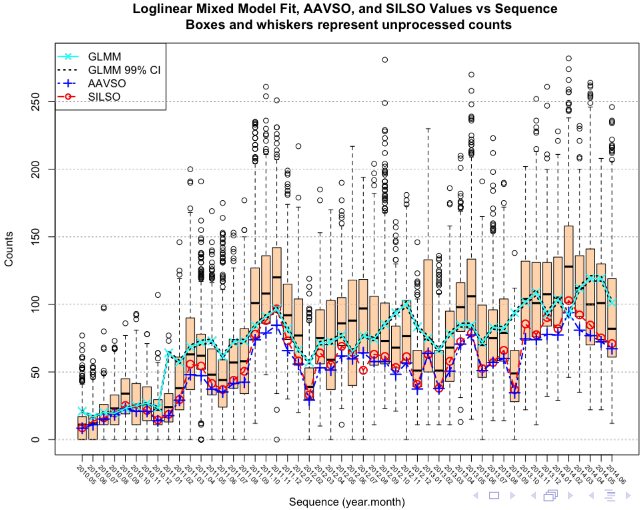
Sunspot Numbers

- Sunspot counts vary by observer, weather conditions, place in the sunspot cycle, etc.
- Monthly estimates are from a mixed effects, loglinear model constructed from these Poisson-distributed count data
- This model differs from existing models used by AAVSO and SILSO
- The loglinear model methodology meets or exceeds established performance criteria
- Loglinear model addresses uncertainty explicitly unlike the implicitness of AAVSO

Daily sunspot counts for June, 2014



Sunspot counts from May 2010 through June 2014

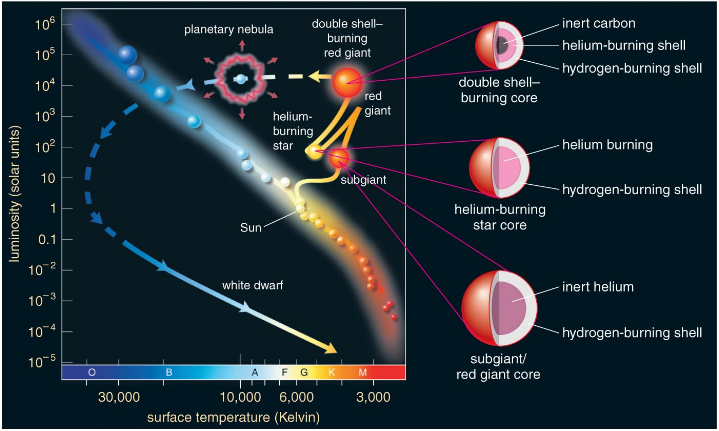


Mira Masers and Proto-Planetary Nebulei

OH/IR Stars

- An OH/IR star is an evolved late type star showing OH maser emission which is bright at near infrared wavelengths.
- Miras with short pulsation periods (about one year) and low mass loss rates produce weak masers in the 1667 MHz line
- Miras with a high mass loss rate and long pulsation periods (up to six years), the 1612 MHz hydroxyl masers becomes much stronger than the 1667 masers
- Known as OH/IR stars for their strong hydroxyl (OH) masers and strong infrared (IR) emission from the shell of warm gas.
- The intensity of the maser follows the changing brightness of the star as it pulsates.

OH/IR Star: Asymptotic giant branch star with dust-rich wind and 18 cm OH maser emission

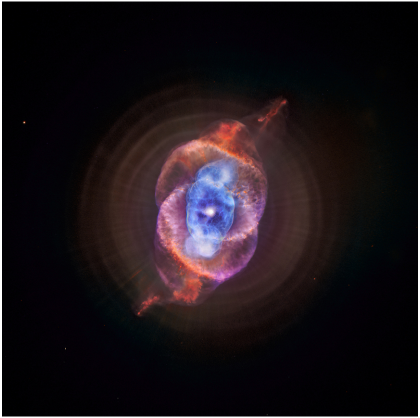


Proto-Planetary Nebula

- A proto-planetary nebula (PPN) is a star with rapid stellar evolution
- Falls between the late asymptotic giant branch phase and the subsequent planetary nebula phase
- A PPN emits strongly in infrared radiation
- It is the second-from-the-last high-luminosity evolution phase in the life cycle of intermediate-mass stars (1-8 Solar masses)

Cat's Eye Nebula

Example of young planetary nebula with bipolar structure (optical/X-ray image)



Observations with Arecibo

- OH/IR star (IRAS 16260+3454) in 18 cm (on, L-band) and 5 GHz (on, C-band)
- Calibration source (B1622+23) for 5 GHz (position switching)
- PPN (IRAS 18095+2704) in 18 cm (on) and 5 GHz (position switching, three 5 minute integrations)

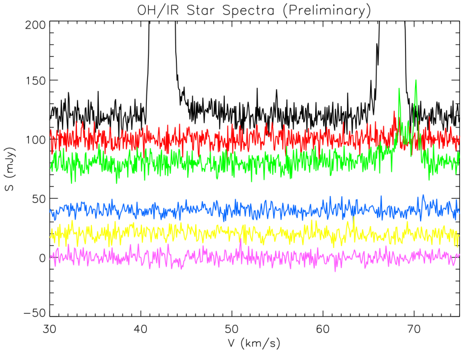
Radio Telescope, Arecibo, PR

Reduction Process

- Calibrating the 5 GHz scale to mJy for each of the three lines and each of their polarizations
- Traditional analysis
  - Formed weighted average of the three integrations for each line
  - Removed polynomial baseline of order 2
- Improved analysis
  - Linear model of three integrations and six lines
  - Accounts for within and across variation
- Plotted intensity vs. velocity

Results: OH/IR Star

- Lines Plotted
  - 1612.2 MHz
  - 1665.4 MHz
  - 1667.4 MHz
  - 4660.2 MHz
  - 4750.7 MHz
  - 4765.6 MHz
- (Note: Scans displaced vertically by 20 mJy for display)



Results: Proto-Planetary Nebula

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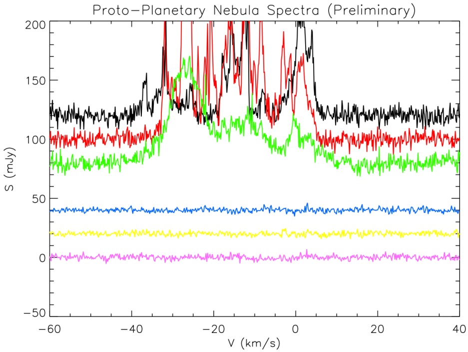
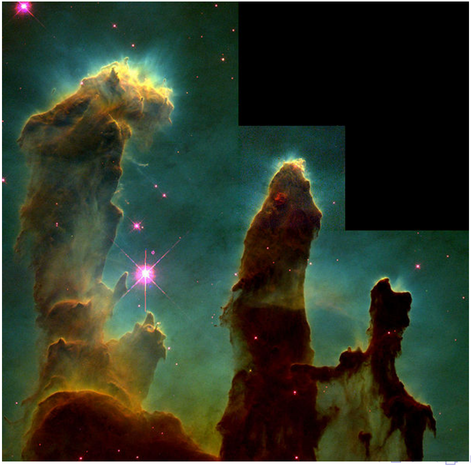


Intermediate- and High-Mass Star Formation

Hubble telescope image of “Pillars of Creation”, where stars are forming in the Eagle Nebula

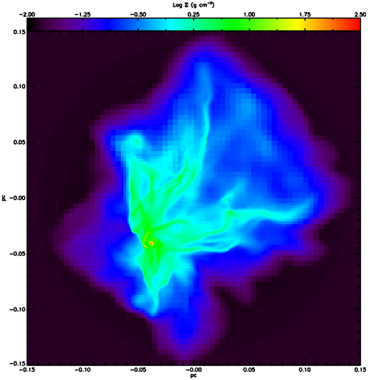


IMSFR and UCHII

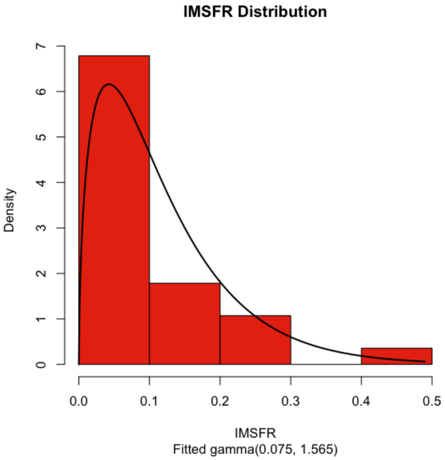
- We wish to understand the factors governing the transition from intermediate- to high-mass star formation
- Arvidsson, et. al., (2010), identified for the first time Intermediate-Mass Star-Forming Regions (IMSFRs) of from 5 to 8 solar-mass stars
- InfraRed Astronomical Satellite observations, Spitzer Space Telescope mid-InfraRed (IR) images, and millimeter continuum were used to compile a sample of 28 IMSFRs in the inner Milky Way
- IR luminosity and molecular mass of IMSFRs are consistent with known luminosity-mass relationships
- Peak mass column densities within IMSFRs are $\sim 0.05 - 0.5 g/cm^2$, lower than most Ultra-Compact HII regions (UCHII).

Column density of a simulated protostellar core 20,000 years after the beginning of gravitational collapse.

(http://www.nersc.gov/news/science/high-mass-star.php)



Histogram Overlaid with Fitted Gamma Distribution



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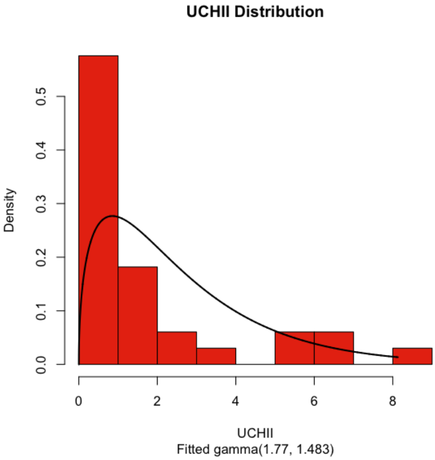
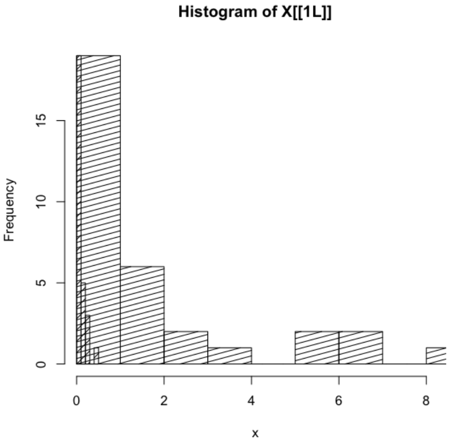
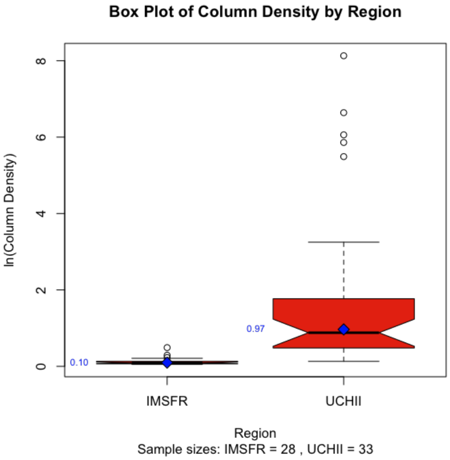


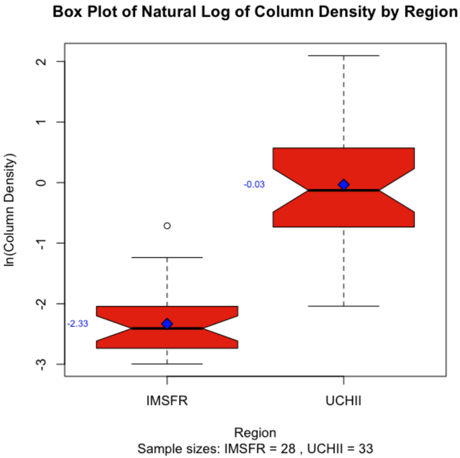
Overlaid Histograms



Box Plots of IMSFR and UCHII Data



Random Effects Model Means Also Clearly Different



Region Demarcation

- Does high-mass star formation occur only if the mass column density is $\geq 1g/cm^2$?
- Does intermediate-mass star formation only occur if the mass column density is $< 1g/cm^2$?
- Given observation uncertainties of a factor of 2, is 1 g/cm^2 a reasonable high mass threshold?
- What can be said of a threshold of 0.7 g/cm^2?
- If the sample size is increased in each sample, how does the conclusion change?

Region Probabilities

Table : Includes Observing Error

i	ρ_i	$P(IMSFR \mid \rho > \rho_i)$	$P(UCHII \mid \rho < \rho_i)$
1	0.35	0.0282	0.0612
2	0.70	0.0004	0.1526
3	1.40	0.0000	0.3425
4	0.50	0.0045	0.0989
5	1.00	0.0000	0.2354
6	2.00	0.0000	0.4860

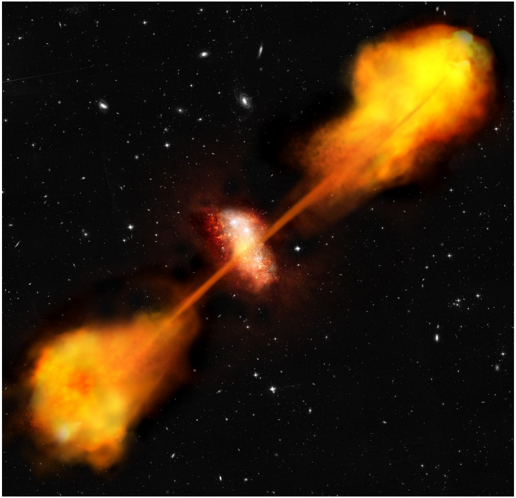
Conclusion

- Decide a high-mass star formation threshold and the physics behind it
- Request a statistical argument (have a bunch of astrophysical ones) to address the threshold question
- Does the overlap of densities depend on the number of massive stars in the region?
- What is a suitable sample size (design)?

Intermediate and High Mass Star Formation

Radio-Active Galactic Nuclei Cosmology

Herschel AGN radiogalaxy



What is a Radio-Active Galactic Nucleus?

- An active galactic nucleus (AGN) is a compact region at the center of a galaxy that has a much higher than normal luminosity, specifically radio emission
- A galaxy hosting an AGN is called an active galaxy
- The radiation from AGN is believed to be a result of accretion of mass by a supermassive black hole at the centre of its host galaxy
- Radio-AGN evolution is a function of cosmic time also puts constraints on models of the cosmos.
- Simulated radio-AGN universe catalogs are generated, then compared to the observed radio-AGN galaxy catalog
- The simulated catalog has flux density and lobe separation effects are compared to the corresponding observed radio-AGN catalog

Herschel AGN radiogalaxy